Progress Report

Grant #731009
Ultra-Efficient Generators & Diesel Electric Propulsion
Genesis Machining & Fabrication
Reporting Dates: 1/2014-3/2014

Deliverables Submitted:

Budget:

Being submitted separately with permission from project manager.

Schedule Status:

We are a little behind schedule because it has taken the full quarter to select an appropriate engine and the engine has a three month lead time. The result of this is that we will not be able to start building the bus scale genset yet. However, we have been working very hard on the TRL-7 design and will have plenty of work to do until the engine comes.

Work Progress:

1. Engine Selection

We have selected a 215hp Cummins Tier 3 diesel power unit for our bus scale variable speed genset. We have established a relationship with Cummins Northwest for our project and they have offered a $2.5k sponsorship for the power unit.

2. Gearbox Design

Our genset requires a high efficiency gearbox between the diesel engine and the power-dense generator head. We have made some inroads into the gearbox design and have found a manufacturer / design house to cut the gears. This company has established the feasibility of the gearbox. We still have further design work to do to before we can proceed.

3. Heatsink Redesign

In our last report we discussed heatsink design. Further simulation work has revealed the inadequacy of the heatsink design and we have revised it over this quarter. We have developed two solutions: 1) a high cost, ultra-high performance aerospace grade heatsink solution, and 2) a low cost, high performance solution. The first uses open-cell silicon-carbide (SiC) foam as a heatsink medium. We have validated that we can, in fact, produce a heatsink based on SiC foam but the cost would be upward of $1k / heatsink. We may build such heatsinks in the future as a high performance option.

Fig.1 - Open-cell Silicon Carbide foam sample

The second option uses an aluminum pin-fin concept. Pin fins maximize turbulence which is essential for heat transfer. They also have a much higher surface area than traditional fins. The problem is that pin-fin material is hard to buy pre-made. Therefore, we have built a tool to cut the pin-fin heatsinks for the TRL-7 inverters. We also identified and purchase commodity pin-fin heatsink blanks but subsequently realized that it was cheaper for us to make them ourselves. In fact, our tool (right-angle milling head, arbor, and blades) will pay for itself simply by cutting the heatsinks needed for the inverter stack going in the bus.

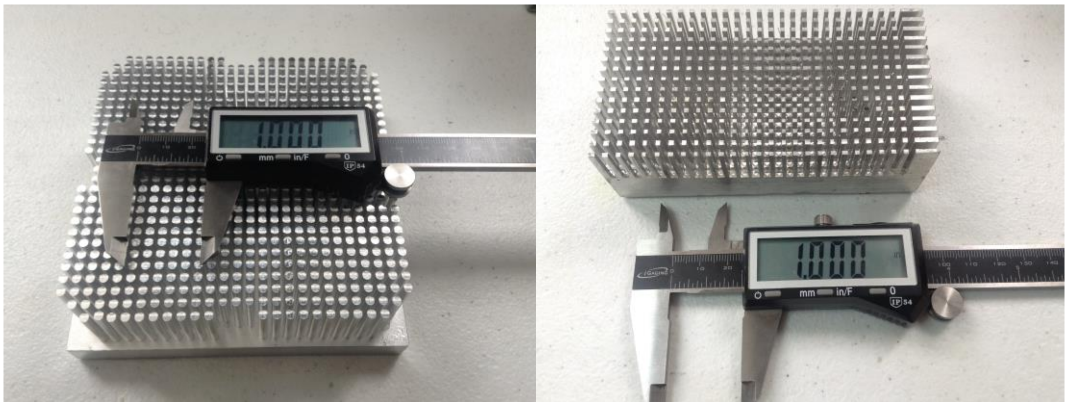

Fig. 2 – Left: Commodity pin-fin design. Right: In-house pin fin material.

Figure 2 shows the commodity pin-fin material compared to our own pin-fin. Square pins are easier to manufacture and also induce more turbulence into the heat-transfer medium. We have successfully tested our pin cutting method on the block shown in Fig. 2 (right) and Fig. 3.

Fig. 3 – Pin-Fin Cutting arbor

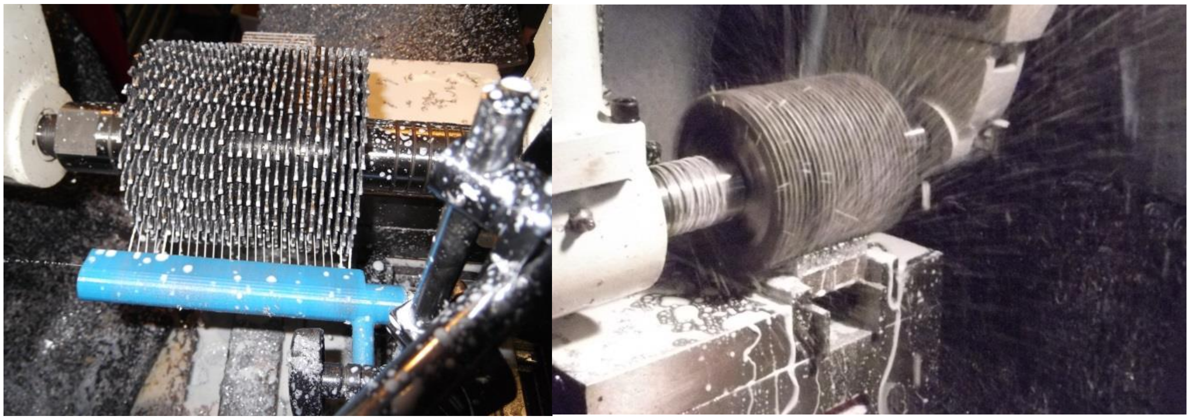

Fig. 4 – Left: Cutting arbor and coolant spayer. Right – Cutting arbor in action!

A video of the heatsink cutter can be seen at: http://www.youtube.com/watch?v=1A4A9z6TjmE

Another complexity of the heatsink is the coolant plenums. The tight space constraints in the TRL-7 inverter assembly required the design of complex plenums to bring coolant to and from the heatsink. We have been able to successfully use Fused Filament Fabrication (i.e. 3d printing) to build a prototype plenum from ABS plastic. These plenums will be good to temperatures of 95^{o}C, which is adequate for most inverter applications. We will adopt a higher temperature solution in the future when we move into volume production.

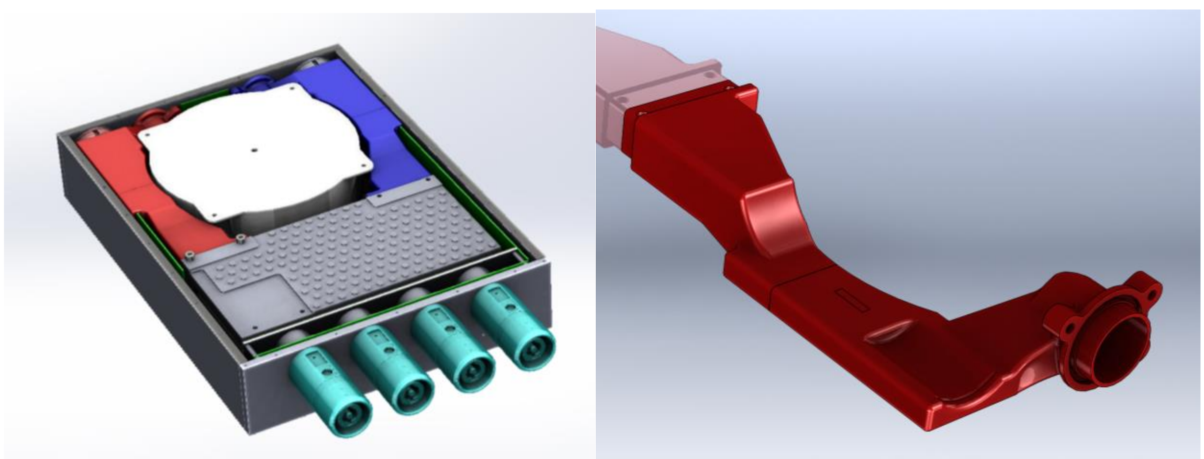

Fig. 5 – Left: TRL-7 bottom view space constraints. Right: Coolant Plenum

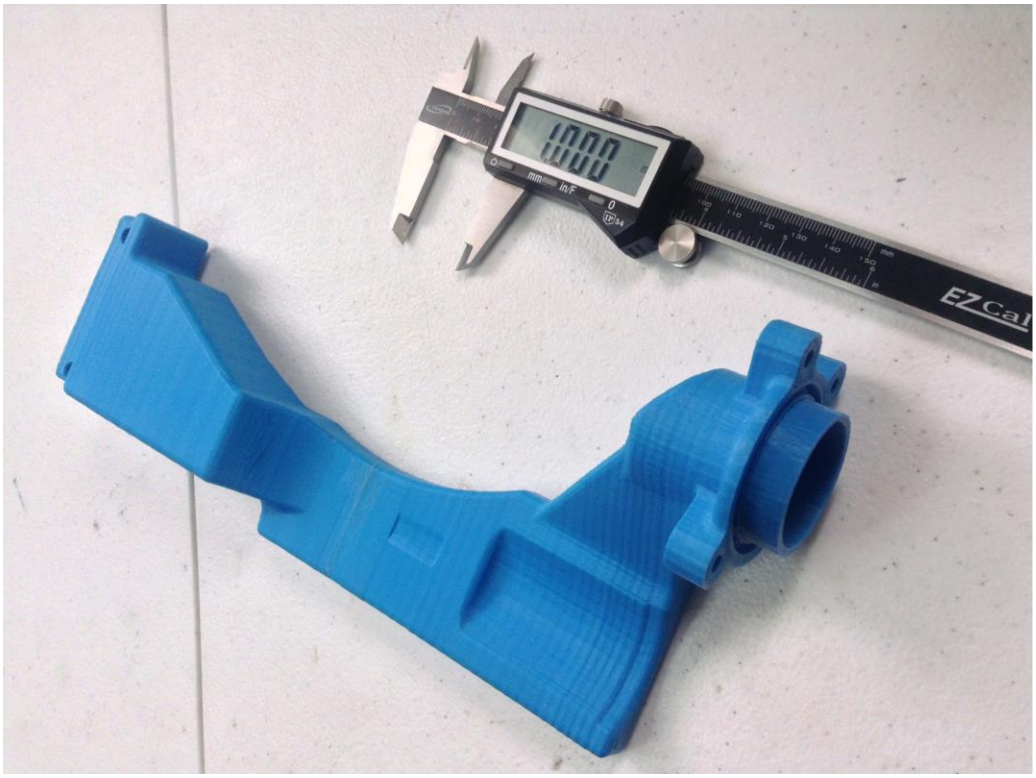

Fig. 6 – ABS plenum made with FFF technique.

Another design hurdle facing the heatsink design was the Thermal Interface Materal (TIM) forming the heat conduction path from the IGBT semiconductors to the heatsink. The traditional silicone TIM used in the TRL-6 inverters proved inadequate when studied with our thermal simulations. Silicone is prone to creep over time and the thermal interface will degrade with time and thermal cycling. Several solutions were studied including diamond paste, liquid gallium TIM, indium foil TIM's, and a new proprietary material known as SNPlus from Indium Corp. While gallium is being marketed for high performance IC's, our research showed that it could eventually attack the copper baseplates of the IGBT's. The indium foil solution, while offering high performance proved to be quite expensive. A lower cost alternative found with Indium Corporation's proprietary SNPlus material, which has a thermal conductivity nearly 10 X that of traditional TIM's. Samples have been provided and we will be testing them in a prototype TRL-7 heatsink.

This metal foil TIM is based on clamping pressure between the device and the heatsink. We have started studying the clamping pressure using a product known as Prescale from Fujifilm. Prescale paper gives a visual plot of clamping pressure and will allows us to measure the clamping pressure on the SNPlus material. Figure 7 shows the uneven pressure distribution with our current plate design. We are working on solutions to create even pressure distribution.

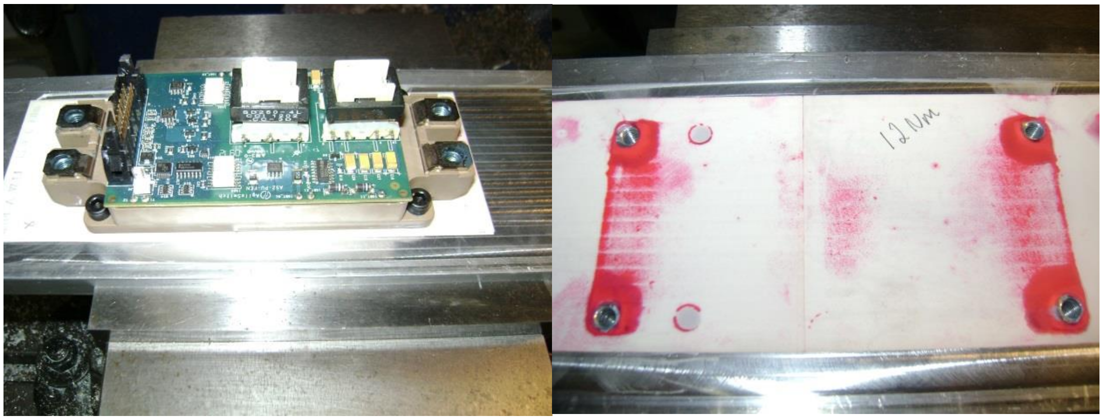

Fig. 7 – Left: IGBT clamped to test plate with Prescale film. Right: Film showing uneven pressure distribution. The saturated areas are > 355 psi.

4. TRL-7 Progress

During this quarter the TRL-7 design has gone through several revisions. These include the heatsink design, PCB designs, communication bus protocol, and how various functions will be distributed among inverter modules. While this process has taken longer than anticipated, we are very happy with the outcome and have a complete mechanical design at this point.

Fig.8 – TRL-7 Inverter module from the input and output sides.

Our PCB layout work has continued with Prof. Bitar and the student group from Worceter Polytechnic Institute. The PCB design has of necessity been revised along with the mechanical design. At this point a complete functional map of all circuits has been produced, as well as detailed PCB layouts of some subcircuits. We anticipate three to six months before all finished and tested PCB's are in hand.

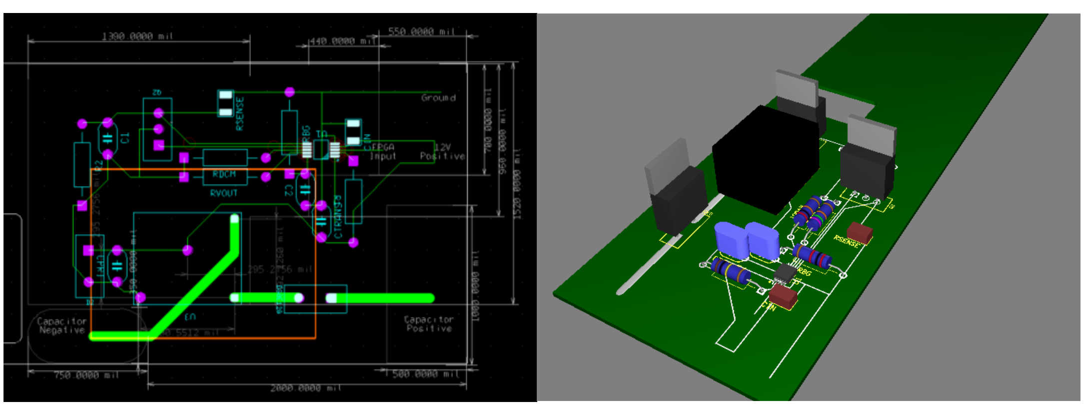

Fig. 9 – Example of student PCB design: Pre-charge circuit for TRL-7 module.

5. AgileSwitch Visit

During this quarter the CEO of AgileSwitch, Rob Weber, visted Kodiak and checked out our project. Agile has been a project partner since the start of our project. During the visit we demonstrated our EV testbed and discussed Agile's SmartStack product, which may be applicable for our work in certain air-cooled applications.

Project computer engineer Seraphim McGann (left) with Agile Switch CEO Rob Weber in Kodiak

6. Large Lathe Purchase

This quarter we were happy to acquire a 20" swing lathe capable of turning the rotors for large power dense motors. We will be using this lathe to modify motors for use on the bus scale generator and propulsion motor. Though old, this lathe has low hours and has been completely rebuilt and refurbished. We were able to purchase it for only $1000, less than it would have cost another machine shop to turn the rotors for the DE bus.

Fig. 10 – 20" swing lathe for cutting rotors

7. Potential Customers

Over the past several months we have been developing relationships with potential customers. One connection is with a company which is implementing a wood-to-diesel conversion technology to help rural communities offset fuel costs. They are interested in 200 kW high-efficiency gensets for their plants. As of now, they would like to see functionality at the Bus-scale level before proceeding to a contract. We have and NDA in place and have had several formal discussions with this group over the past quarter.

Another potential customer is a military application for powering a large cooling pump. We made an informal presentation to this group through a USCG engineer who visited our project last quarter. We have not had any formal discussions with them yet.

Work for Next Quarter

1) Build and validate TRL-7 heatsink design.
2) Design, print, and test TRL-7 PCB designs.